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## 1. INTRODUCTION

In a data assimilation system (DAS), model forecast atmospheric fields, observations and their respective statistics are combined in an attempt to produce the best estimate of these fields. Ozone observations from two instruments are assimilated in the Goddard Earth Observing System (GEOS) ozone DAS: the Total Ozone Mapping Spectrometer (TOMS) and the Solar Backscatter Ultraviolet (SBUV) instrument. The assimilated observations are complementary; TOMS provides a global daily coverage of total column ozone, without profile information, while SBUV measures ozone profiles and total column ozone at nadir only. The purpose of this paper is to examine the performance of the ozone assimilation system in the absence of observations from one of the instruments as it can happen in the event of a failure of an instrument or when there are problems with an instrument for a limited time. Our primary concern is for the performance of the GEOS ozone DAS when it is used in the operational mode to provide near real time analyzed ozone fields in support of instruments on the Terra satellite. In addition, we are planning to produce a longer term ozone record by assimilating historical data. We want to quantify the differences in the assimilated ozone fields that are caused by the changes in the TOMS or SBUV observing network. Our primary interest is in long term and large scale features visible in global statistics of analysis fields, such as differences in the zonal mean of assimilated ozone fields or comparisons with independent observations. While some drifts in assimilated fields occur immediately, after assimilating just one day of different observations, the others develop slowly over several months. Thus, we are also interested in the length of time, which is determined from time series, that is needed for significant changes to take place.

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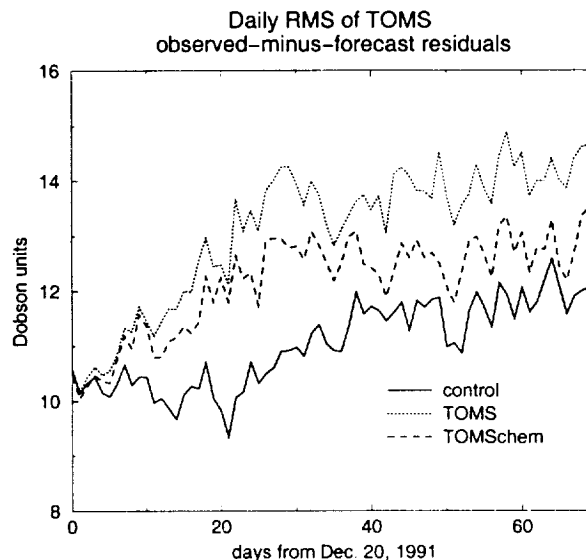


Figure 1: Daily root-mean-square difference between TOMS observed and forecast total column ozone for the experiments assimilating TOMS data.

## 2. EXPERIMENTS

The impact of withholding data from one of the instruments in the GEOS ozone DAS is studied by comparing products of the following four data assimilation experiments. The experiment called "control" uses the GEOS ozone DAS in its usual configuration described by Štajner et. al. (1999), where the TOMS total column ozone and the SBUV partial ozone profiles are assimilated into an ozone transport model. In the "SBUV" experiment the SBUV total ozone and partial profile observations are assimilated into the transport model. In the "TOMS" experiment the TOMS total ozone data are assimilated into the ozone transport model. This configuration is expected to produce large errors in ozone profiles especially in the upper stratosphere and mesosphere where photochemical time scales are shorter compared to lower stratosphere and troposphere. Accumulation of significant errors is expected in a two months long experiment because neither observations nor chemical model is constraining the profiles. Thus, in the last experiment, "TOMSchem", the TOMS total ozone data are as-

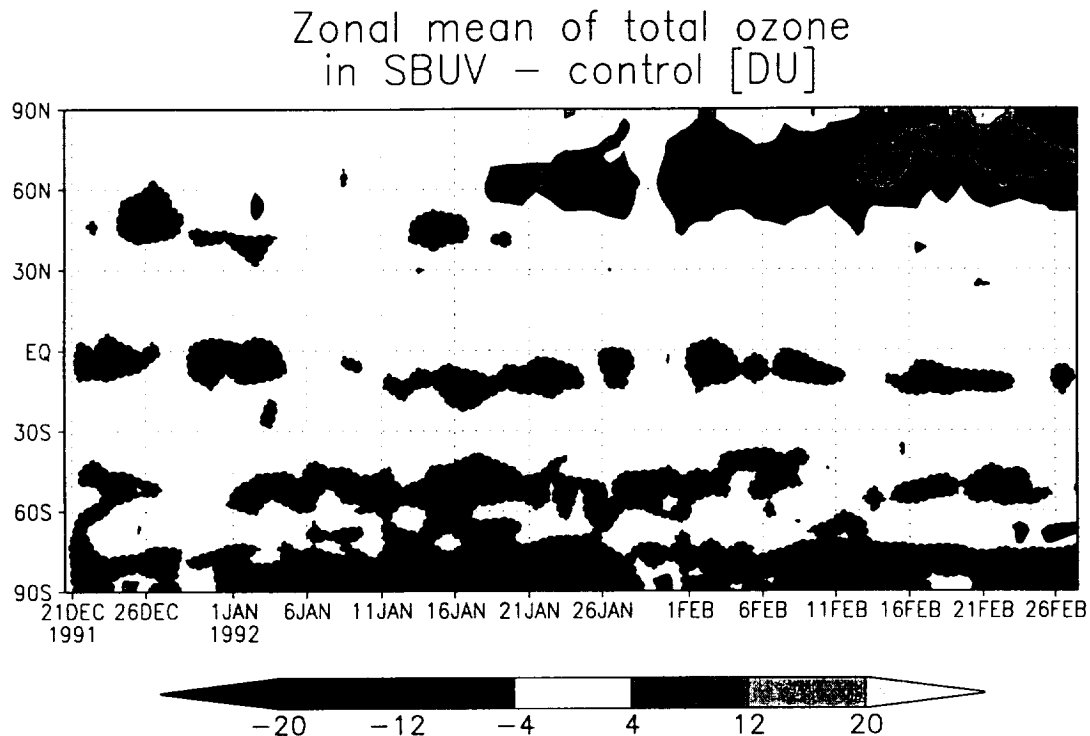


Figure 2: Time series of zonal mean difference between total column ozone in the SBUV and control experiments.

simulated into a parameterized chemistry and transport model. This model is similar to the one described in Riishøjgaard et. al. (1999). The parameterized chemistry consists of ozone production and loss rates tabulated by latitude, altitude and month, with loss rates as in Riishøjgaard et. al. (1999), and production rates adjusted in order to have the quotient of production and loss rates equal to the monthly mean of Halogen Occultation Experiment (HALOE) observations above 10 hPa (A. Douglass, personal communication). Note that HALOE measurements are not available in near-real-time, so that the use of the *TOMSSchem* assimilation in near-real-time and for historical data prior to the HALOE measurements remains to be investigated. All the experiments start from the same initial condition on December 20, 1991 that was obtained by a week long assimilation of TOMS and SBUV data using the configuration of the control experiment. Assimilation experiments end on February 28, 1992.

### 3. RESULTS

In the first part of the comparison we quantify the effects on the total column ozone analysis. Daily root-mean-square (RMS) of the differences between TOMS observations and model forecast of total column ozone

is shown in Fig. 1 for the three experiments in which TOMS data were assimilated. The RMS in Fig. 1 for the *TOMS* and *TOMSSchem* experiments are higher than for the *control* experiment by about 2 DU (Dobson units) and 1 DU, respectively. Thus, withholding of the SBUV observations degrades the total column ozone forecast. When SBUV observations are withheld the total column ozone forecast is more accurate if the parameterized chemistry is included in the forecast model.

In the experiment *SBUV* the SBUV instead of TOMS total column ozone observations are assimilated. The impact on analyzed total column ozone (shown in Fig. 2) is immediate. After only one day zonal means of the *SBUV* and *control* analyses around the south pole differ by more than 12 DU and by more than 20 DU for 20 out of total of 70 experiment days. In contrast, differences in the unobserved polar night region develop slowly. On February 21 (after two months of assimilation) zonal mean difference at the north pole exceeds 20 Dobson units.

The zonal RMS difference between total column ozone in the *SBUV* and *control* analyses (not shown) remains below 8 DU for most of the globe after the initial jump from 0 DU to about 4 DU in one day. Larger RMS differences occur in southern high latitudes while

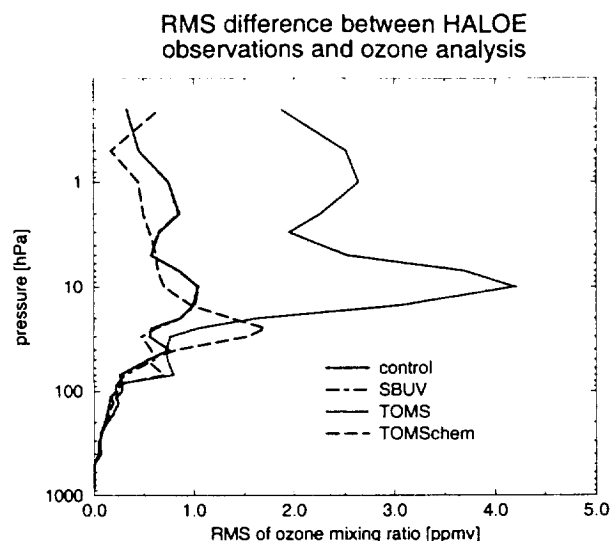


Figure 3: The root-mean-square difference between sunrise HALOE observations and analyzed ozone mixing ratio from January 15 to February 27, 1992.

in the northern hemisphere larger values are initially in middle and shifting to high latitudes in February.

The remaining comparisons quantify the effects on ozone profiles. The RMS differences between HALOE measurements and analyzed ozone profiles for all four experiments are shown in Fig. 3. The RMS is calculated for 651 HALOE sunrise profiles that were measured at latitudes decreasing from  $49^\circ$  to  $-75^\circ$  in the period between January 15, 1991 and February 27, 1992. All the profiles were measured at pressure of 15 hPa or lower, more than a third reached 50 hPa, but fewer than 25 profiles reached pressure of 85 hPa and higher. Thus, we focus on the comparison at the pressures lower than 85 hPa. The curves for *control* and *SBUV* experiments are almost indistinguishable except at 30 and 40 hPa where the *SBUV* is closer to HALOE than *control*. There is also better agreement in the mean ozone between *SBUV* analysis and HALOE than between *control* and HALOE at these levels (not shown). Thus, withholding of TOMS observations has a marginal (positive) impact on the quality of analyzed stratospheric and mesospheric ozone profiles.

In the *TOMS* experiment the quality of profiles degrades significantly compared to the *control*. Large errors are present at all levels above 30 hPa with the RMS exceeding 4 ppmv at 10 hPa. At this level there is an excessive accumulation of ozone at high southern latitudes. The zonal mean of *control* and *TOMS* ozone analysis at 10 hPa on February 27 is shown in Fig. 4. Note the value of over 14 ppmv at  $76^\circ$  latitude south in the *TOMS* ozone analysis.

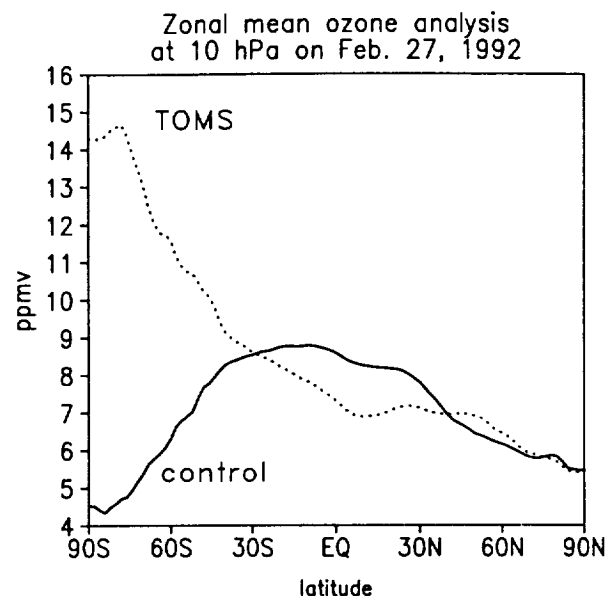


Figure 4: Zonal mean of analyzed ozone at 10 hPa on February 27, 1992 in experiments *TOMS* and *control*. Note excessive accumulation of ozone at southern high latitudes in the *TOMS* experiment.

Recall that while HALOE observations are independent observations for the first three experiments, January 1992 mean of HALOE data was used to define ozone production rates above 10 hPa in the experiment *TOMSchem*. Consequently, there is a better agreement of HALOE profiles with analyzed profiles from *TOMSchem* than from *control* in Fig. 3 at most levels above 10 hPa (a larger error at 0.2 hPa is caused by the use of parameterized chemistry rates that were calculated for 0.5 hPa). A peak of over 1.5 ppmv in the RMS for *TOMSchem* at 25 hPa corresponds to a peak in the difference between *TOMSchem* and HALOE means (not shown) of about 1 ppmv. This feature might be eliminated if ozone production rates in *TOMSchem* between 40 and 10 hPa were adjusted using HALOE mean as it was done for the rates above 10 hPa. The stratospheric and mesospheric profiles of *TOMSchem* still remain to be validated against independent ozone profile measurements.

The quality of the tropospheric part of the profile is similar in all four experiments. The RMS difference between WMO ozone sonde measurements and analyzed ozone profiles relative to the mean of sonde measurements in *control* (not shown) mostly increases with pressure between 10 and 850 hPa: from less than 15% at 20 and 30 hPa, to about 55% at 130 hPa, decreases to about 40% at 200 hPa, and increases

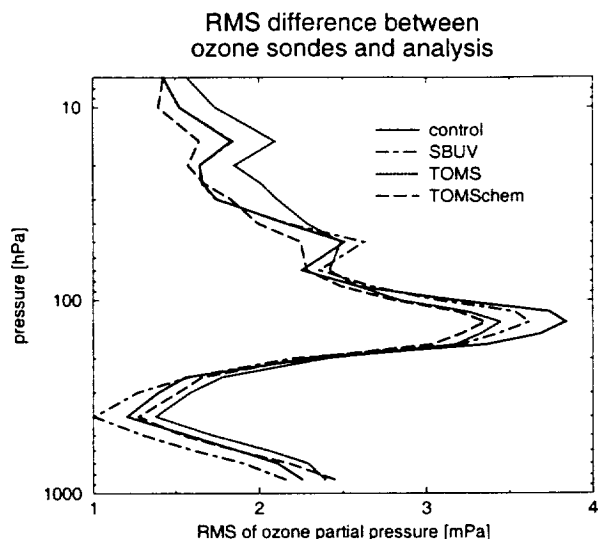


Figure 5: The root-mean-square difference between ozone sonde observations and analyzed ozone partial pressure [mPa] in January and February, 1992.

again to 75% at 850hPa. The RMS differences between WMO ozone sonde measurements and analyzed ozone profiles for all four experiments are shown in Fig. 5. At pressures higher than 250 hPa the RMS for *SBUV* is smaller than for *control*, which is in turn smaller than the RMS for *TOMS* and *TOMSchem*. Around the tropopause and in the lower stratosphere (130 hPa) the *TOMSchem* is in the best agreement with the sondes. In *TOMSchem* the profile shape is mostly determined by the parameterized chemistry and dynamics and it has the weakest dependence on assimilated observations among the four experiments in the comparison. Note that the largest improvements from *control* to *TOMSchem* are at the altitudes 130, 50 and 15 hPa, all of which are near the boundaries of Umkehr layers for which *SBUV* partial ozone column observations are reported. The RMS differences at pressures smaller than 50 hPa are largely consistent to the RMS differences with HALOE: *TOMSchem* is smaller than, *SBUV* almost identical to, and *TOMS* larger than the *control*. However, at 30 hPa, the RMS difference between *TOMSchem* and sondes is about 5% larger than the RMS difference between *control* and sondes, while the RMS difference between *TOMSchem* and HALOE is about 270% larger than the RMS difference between *control* and HALOE. This discrepancy results from distributions of the HALOE and ozone sonde data used in the comparisons. Most of the ozone sonde stations are in the northern, and most of the HALOE sunrise observations in February of 1992 are in the southern middle to high latitudes.

#### 4. CONCLUSIONS

The quality of analyzed ozone profiles (measured by the closeness to the independent ozone sonde and HALOE observations) in the *control* and *SBUV* experiments is very similar. While for most of the globe zonal mean of total ozone analyses in *control* and *SBUV* experiments agree within 4 DU, discrepancies of over 20 DU occur in polar regions. Thus, withholding of TOMS observations has marginal effect on ozone profiles, but substantial differences are seen in total ozone in polar regions and they occur after only one day of assimilation.

Withholding of *SBUV* observations in the experiment *TOMS* where ozone is advected as a passive tracer results in degradation of stratospheric profiles, most noticeable in extensive accumulation of ozone at 10 hPa near the south pole.

Withholding of *SBUV* observations while constraining the profile shape through parameterized chemistry (in *TOMSchem*) slightly degrades the total ozone forecast. Validation against HALOE shows improvements over profiles in the *control* experiment in the upper stratosphere, and degradation around 30 hPa. However, validation of profiles in upper stratosphere and mesosphere against independent observations remains to be done.

#### ACKNOWLEDGMENTS

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